Verity INSTRUMENTS, INC.

SPECTROGRAPHS
ADVANCED PROCESS CONTROL
PLASMA DIAGNOSTICS

Heterodyne Reflectometry for Angstroms-thick Thin Films

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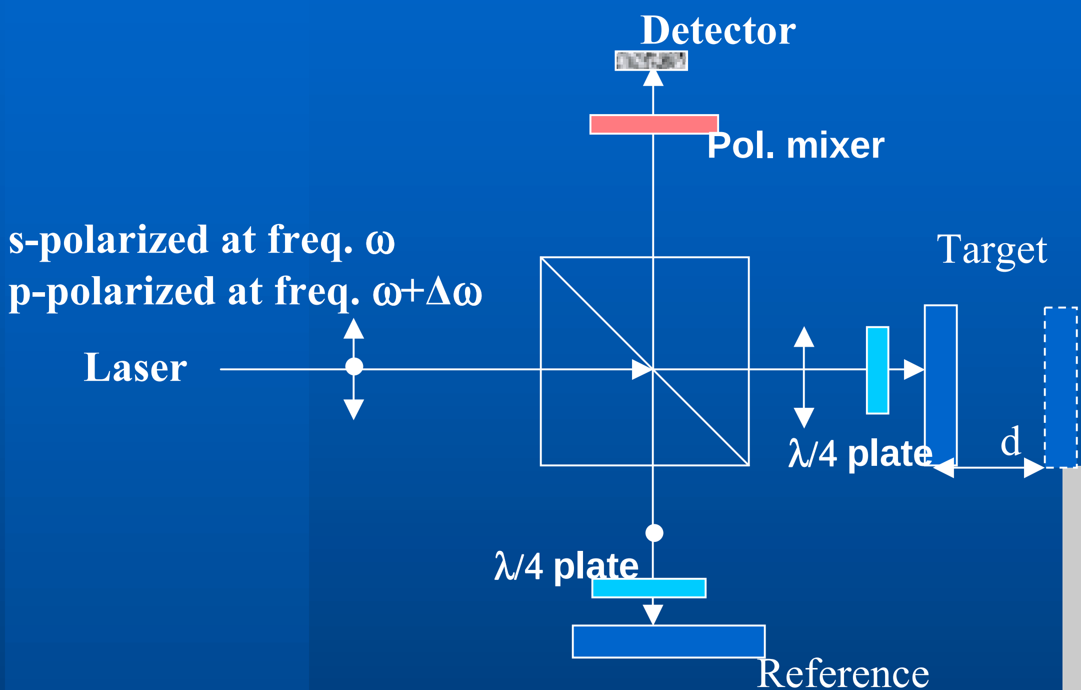
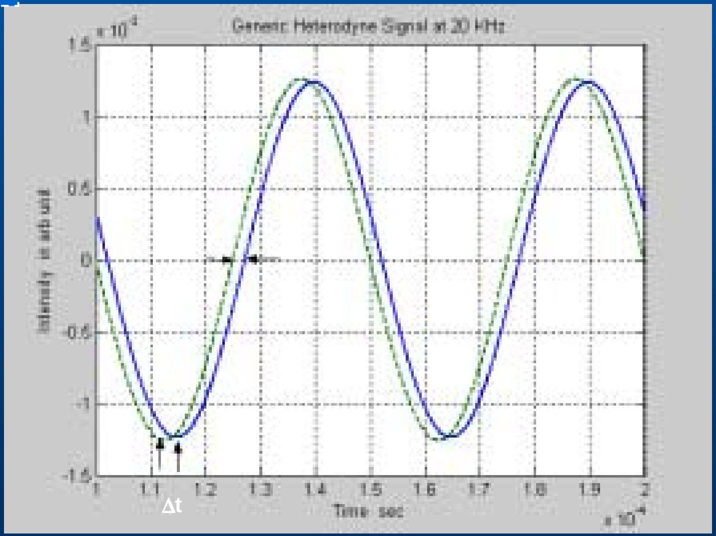
AEC /APC Symposium September 2005

Outline

- **Classical Heterodyne Interferometer (HI)**
- **Adapting HI for Reflectometry**
- **Heterodyne Reflectometer (HR) Results**
- **Difference between HR and Ellipsometer**
- **Advantages**

Classical Heterodyne Interferometer

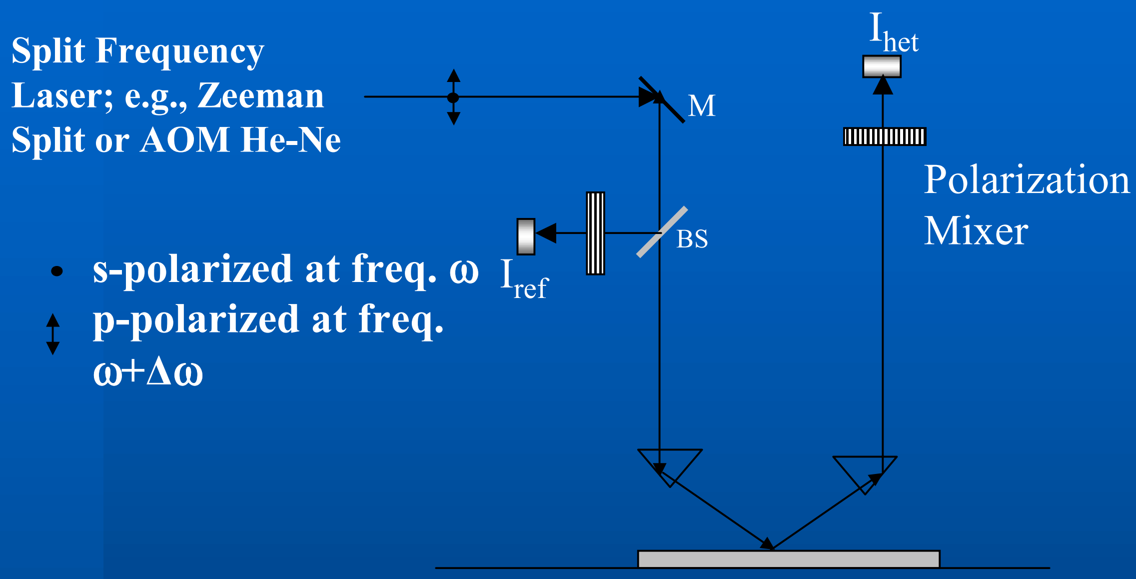




$$S = A + B \cos(\Delta\omega t + \phi)$$

$$\phi = \Delta\omega.\Delta t = 4\pi.n.d/\lambda$$

Heterodyne Reflectometer (HR)



Employs single wavelength at fixed incidence angle

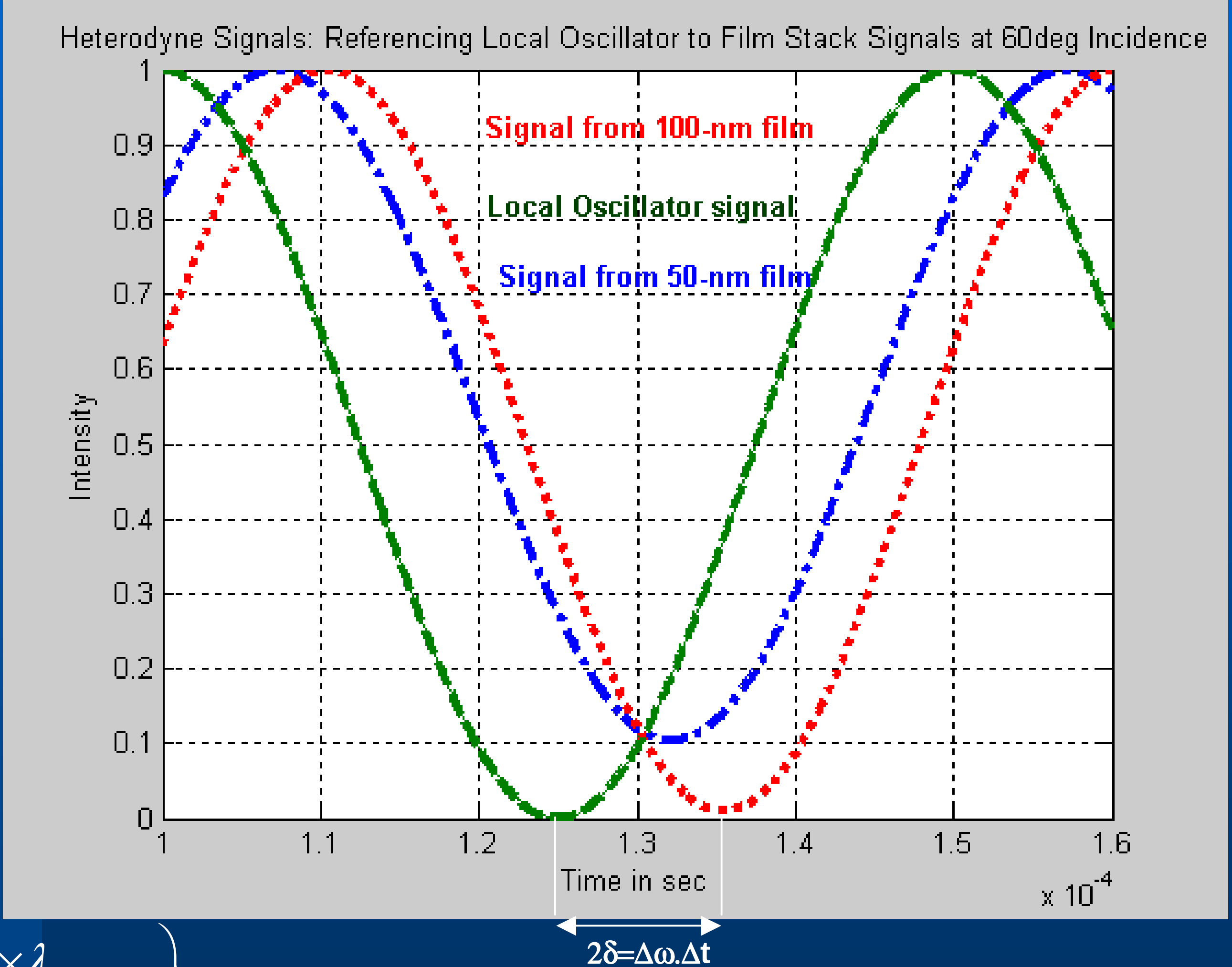
Dynamic range >0 - 1000Å. Extendable by switching λ

Current theoretical resolution of ~ 0.5Å

Roadmap in place to improve resolution to 0.05Å

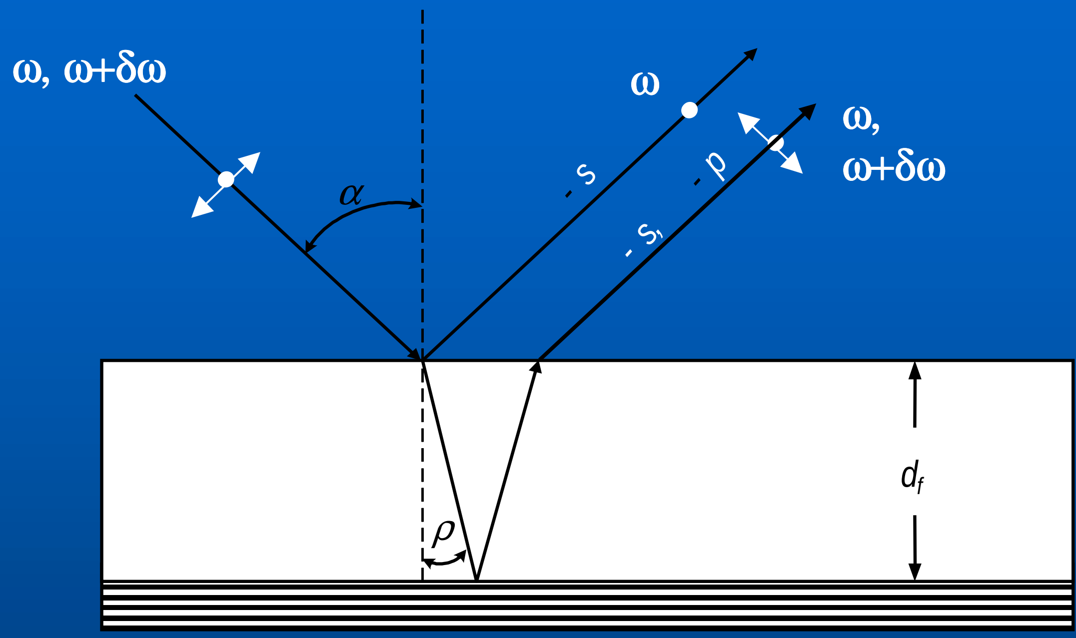
Unlike ellipsometry HR measures thickness directly

Computed HR Signal



$$\left(d_f = \frac{2\delta \times \lambda}{4\pi \times \sqrt{n^2 - \sin^2 \alpha}} \right)$$

Physics of Heterodyne Reflectometer

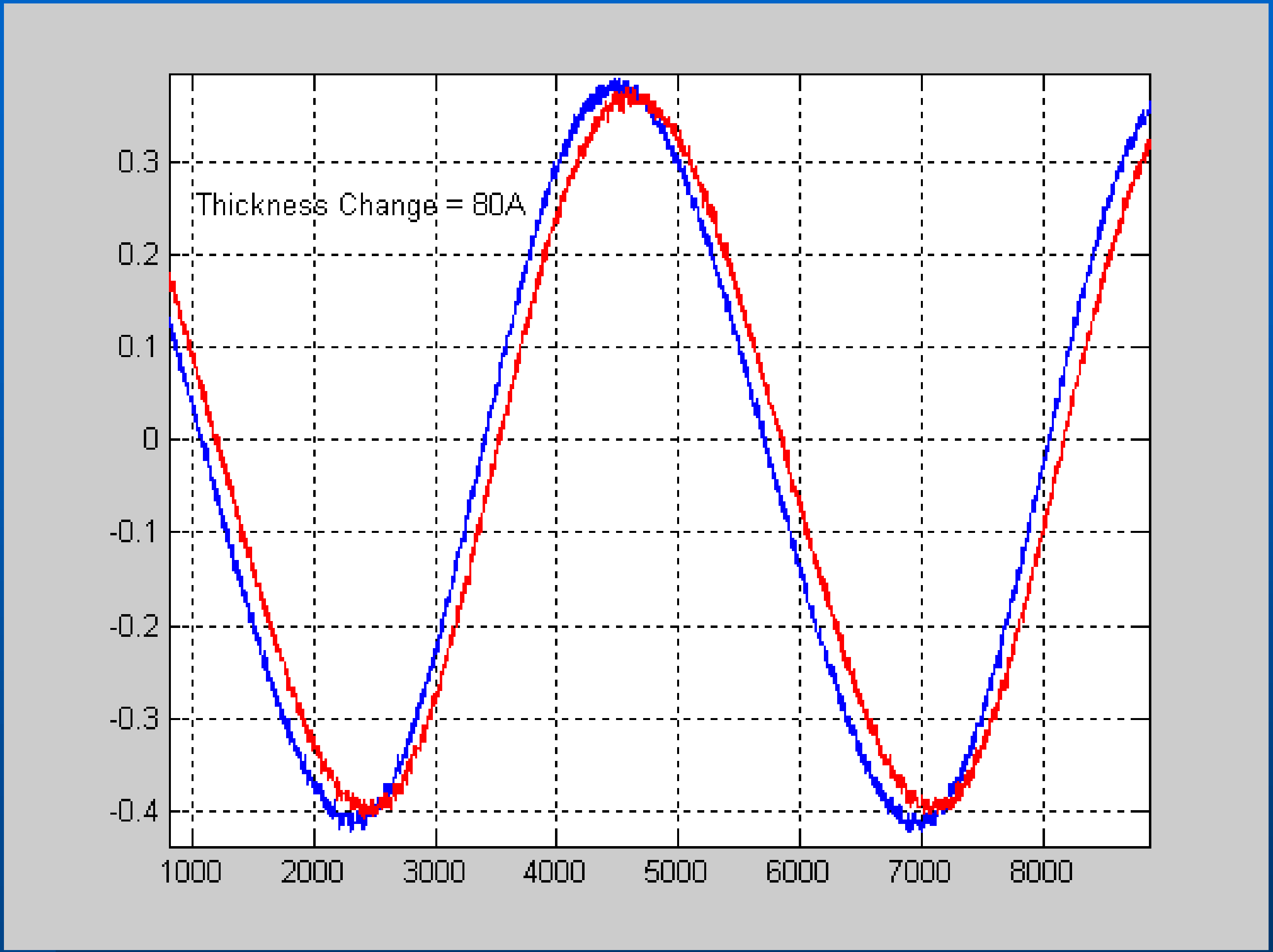


When α is Brewster's angle, only s- polarization (ω) is reflected from top surface and p- polarization is transmitted into the film and reflected by the substrate.

Interference between this s- pol. and p- pol (ω+δω) reflected by the interface will generate a beat frequency at Δω.

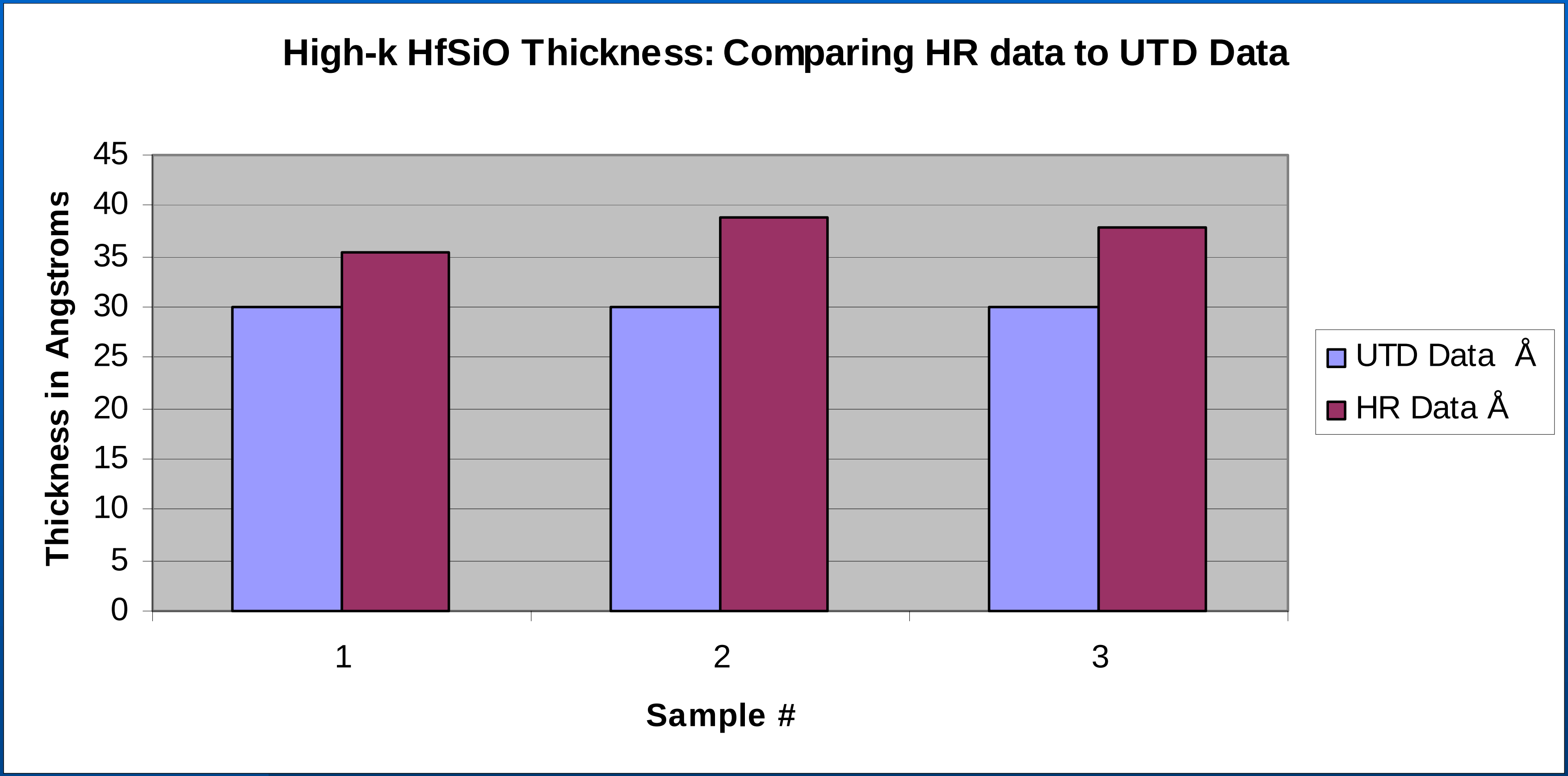
$$R_{eff} \approx \mathrm{K} \times \cos(\Delta\omega t + 2\delta) \qquad \delta = \frac{2\pi \times d_f \sqrt{n^2 - \sin^2\alpha}}{\lambda}$$

Measured HR Signal



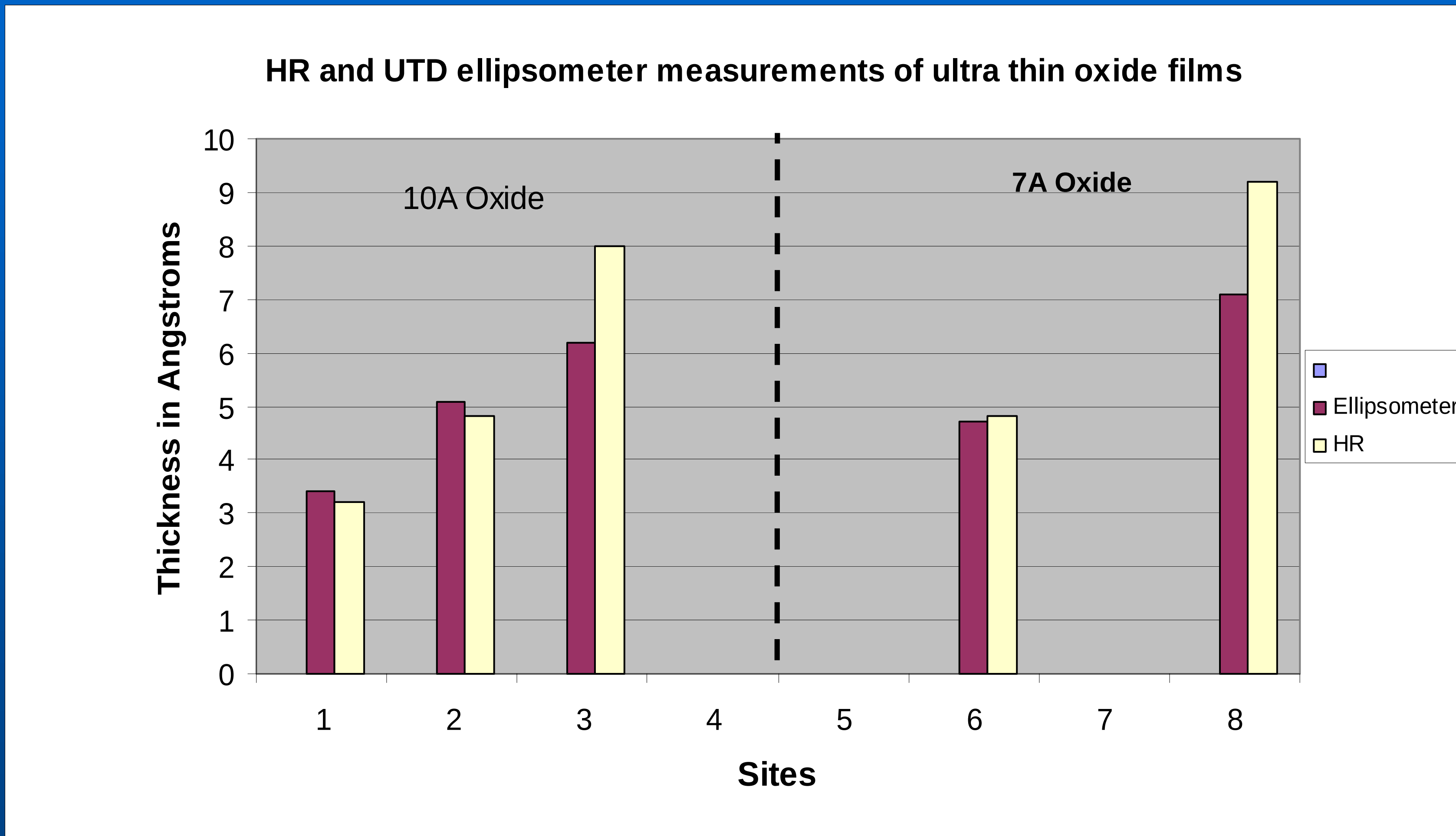
$$d_{sample} = \frac{d_{ox} \times \sqrt{n_{ox}^2 - \sin^2 \alpha} + 2\delta \times \lambda / 4\pi}{\sqrt{n_{sample}^2 - \sin^2 \alpha}}$$

HR Data vs. Ellipsometer Data. Sub 100Å films



Ellipsometry data provided by Univ. of Texas, Dallas ~ 30 – 31Å
First proof of HR measurement ability

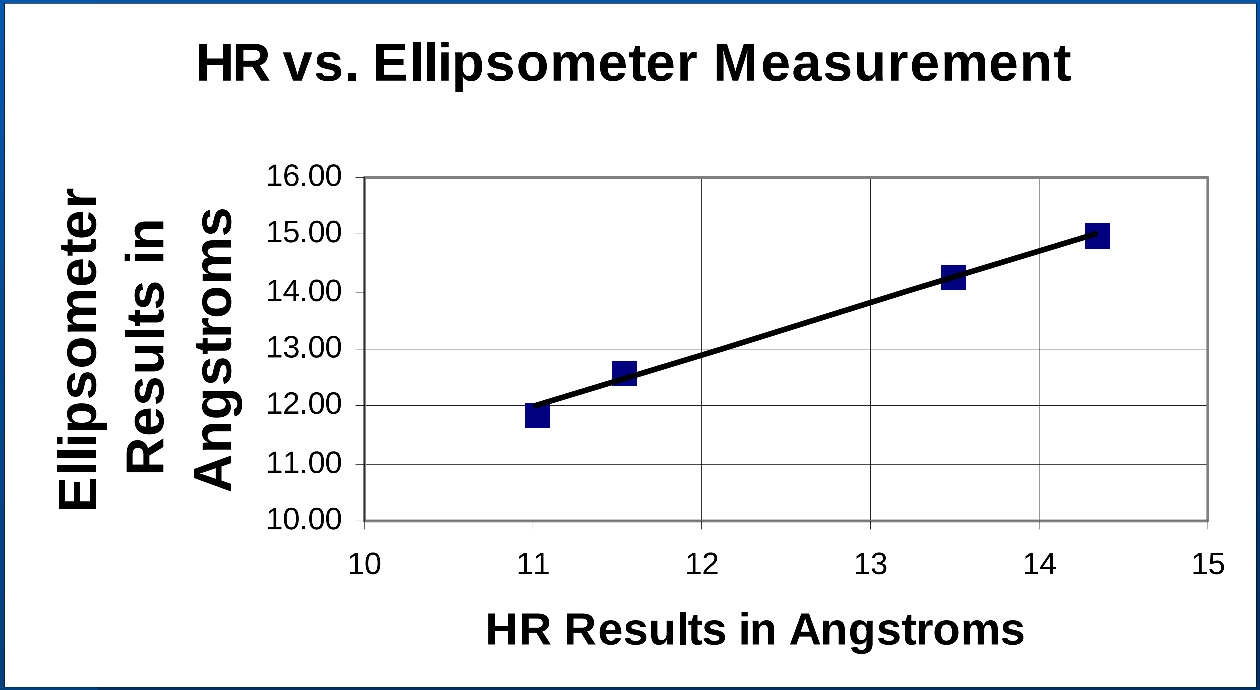
HR Measurement vs. Ellipsometer Measurement sub 10Å films



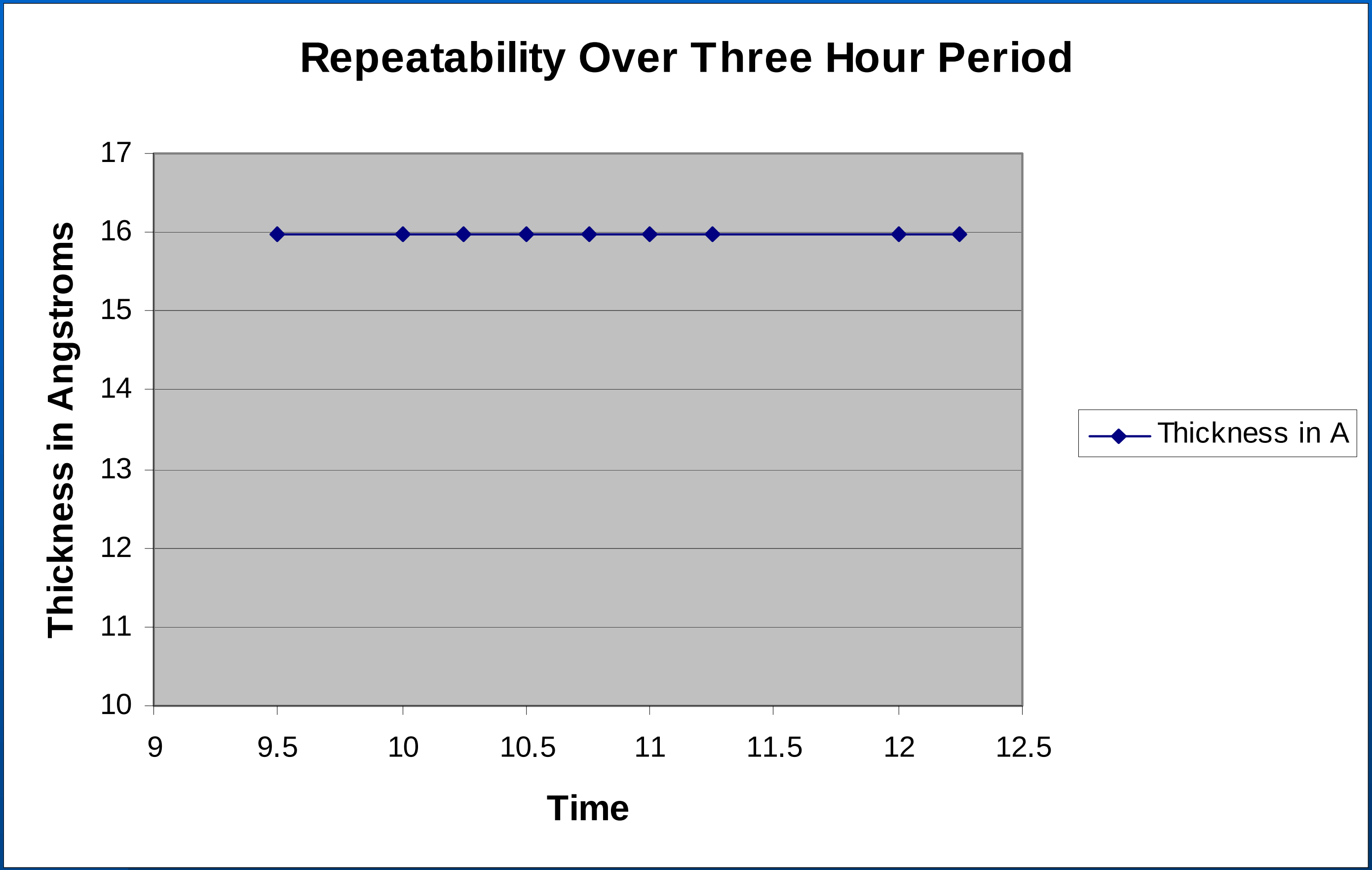
UTD and Verity measured different samples taken from the same wafer

HR measurements of SiO_2 and SiON Films

Description	HR	Ellipsmtr	XPS
	Å	Å	Å
12A oxide	11.01	11.87	11.52
13A oxide	11.54	12.62	12.42
PNO.C2	13.49	14.28	14.76
PNO.C3	14.34	15.01	15.72



HR Repeatability Study



With Current resolution, static repeatability (1σ) better than 0.02%

HR vs. Ellipsometer

HR	Ellipsometer
Uses single λ source at fixed angle	**Uses single λ source at fixed angle**
Measures phase shift 2δ	**Measures ψ and Δ**
d ∝ to measured 2δ $\left(d_f \approx \frac{2\delta \times \lambda}{4\pi \times \sqrt{n^2 - \sin^2 \alpha}} \right)$	**d extracted from thin film model using ψ and Δ** $\tan\psi e^{i\Delta} = \left(\frac{r_{1p} + r_{2p} e^{-i2\delta}}{1 + r_{1p} r_{2p} e^{-i2\delta}} \right) \left(\frac{1 + r_{1s} r_{2s} e^{-i2\delta}}{r_{1s} + r_{2s} e^{-i2\delta}} \right)$
Error in incidence angle has minimal impact on thickness accuracy **0.05Å for 10Å for 1^0 error**	**Sensitivity of Δ is critically dependent on incidence angle**
Uses no moving optical components Larger MTBF	**Mechanically or electro-optically active components used** e.g., rotating compensator, piezo modulator etc.
IM solution possible	**IM solution possible**

Potential Advantages

- Uses single non-actinic wavelength at fixed incidence angle
  - Mitigates photo contamination issues
- Current measurement resolution of ~ 0.5Å
  - Working to improve resolution to ~ 0.05Å
  - Static repeatability (σ) better than 0.02%
- Application: Gate dielectrics, metal films
- Can be integrated with process tool
- Potential exists for retrofitting existing process tool

Acknowledgement

- **Prof. Bob Wallace of UT, Dallas**
  - **for providing thin film samples of Oxide and HfSiO**
  - **for providing ellipsometry data**